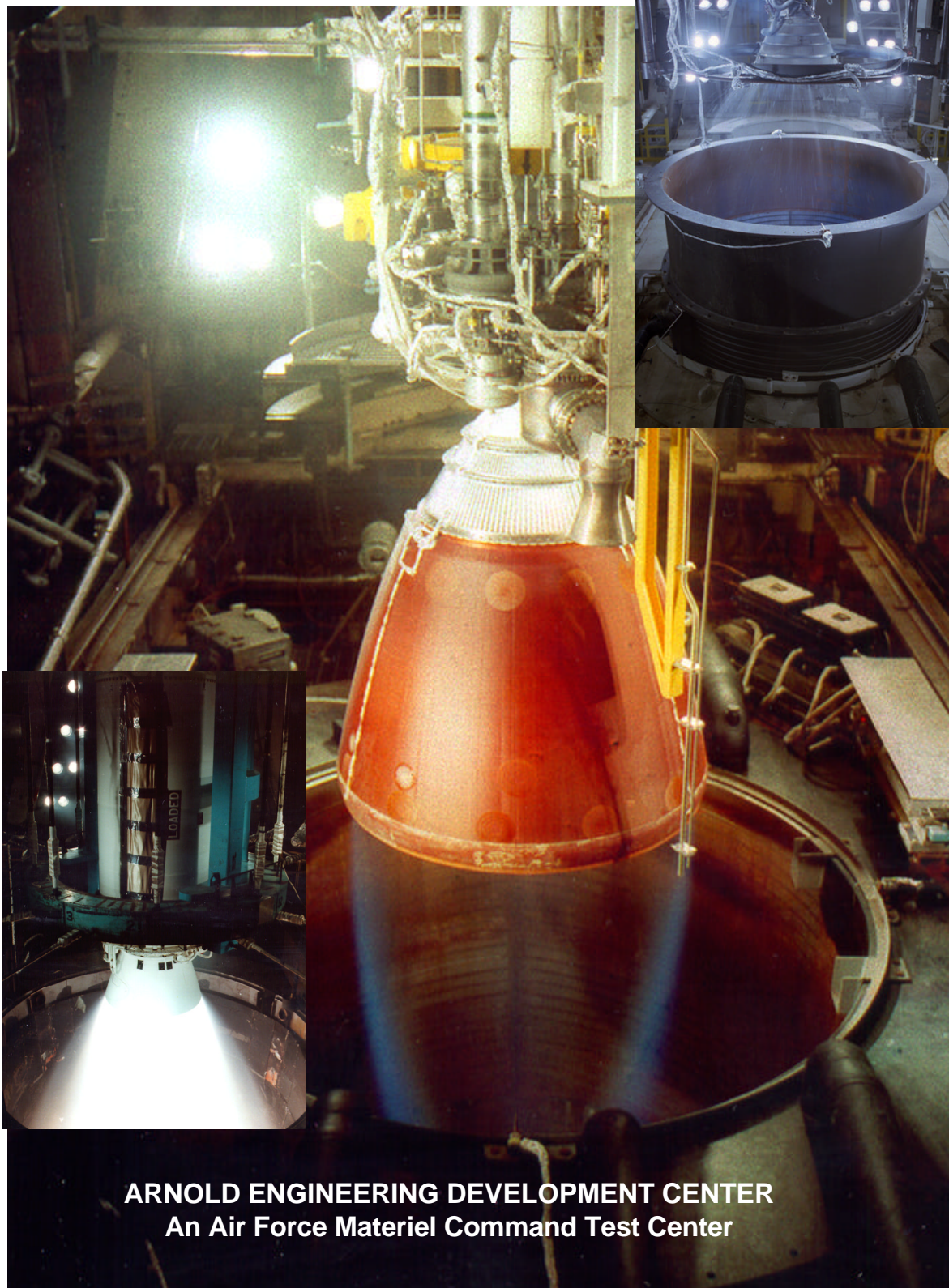


AEDC

Rocket Propulsion

TEST HIGHLIGHTS



ARNOLD ENGINEERING DEVELOPMENT CENTER
An Air Force Materiel Command Test Center

Operator Assistance (931) 454-3000/ DSN 340-5011
Direct Dial (931) 454-XXXX

CATEGORY/EXPERTISE

Point of Contact— Office Symbol/ Phone/ Fax/ Bldg

Propulsion

Rockets

AEDC/DOS/ -7855/ -5804/ MT&L • Performance, Operability, Observability of Solid & Liquid Systems at Simulated Altitude

Turbines & Components

AEDC/DOP/ -7855/ -5804/ ETF • Performance, Operability, Observability & Specialized Testing

- Environmental Testing (Temperatures, Precipitation & Icing)

Re-entry

AEDC/DOS/ -7855/ -5804/ MT&L • Aerothermal Material, Hypervelocity Impact Ablation & Erosion, Wake Physics, Bird Impact

Space • Sensors, Nuclear Weapons Effects, Contamination,

AEDC/DOS/ -7855/ -5804/ MT&L Thermal Vacuum, Infrared Signatures, Space Dynamics

Technology

AEDC/DOT/ -6523/ -3559/ ASTF • Develop New Facility Concepts, Instrumentation, and Test & Analysis Techniques

Aerodynamics

AEDC/DOF/ -7721/ -3339/ PWT • Aircraft/Missile Performance, Stability & Control, Propulsion/Inlet Integration & Compatibility, Store/Stage/Separation, Weapons Carriage, Aero-optics, Signatures

Distribution unlimited: Approved for public release.

Electronic version of **Test Highlights** is available on the AEDC
World Wide Web home page: at <http://www.arnold.af.mil/>

Test Highlights is published by the Office of Public Affairs, Arnold Engineering Development Center (AEDC), 100 Kindel Drive, Suite B-213, Arnold Air Force Base, Tenn., 37389-2213, (931) 454-3000.
Editor: Mark Fearing

ON THE COVER:

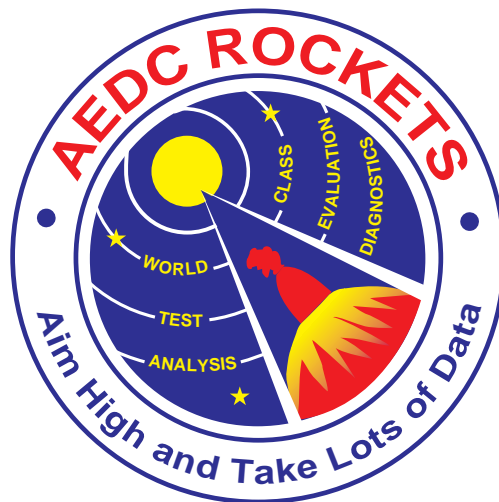
Bottom Left: Peacekeeper Stage II motor

Top Right: Pratt & Whitney RL-10A4 engine for Delta III Launch vehicle.

Background: Titan IV LR91 engine.

Contents

Foreword	2
Philosophy	3
Programs	5
Facility Summary	9
Analysis Tools	15
Modifications	17
Future Plans	19
Related Facilities	20



Foreword

As the nation moves into the 21st century, there is a growing need for cheaper, more available access to space. AEDC is firmly positioned to support this need through our simulated-altitude rocket test and evaluation capability.

Today, AEDC has an unprecedented capability for testing and evaluating rocket engines under simulated altitude conditions. To meet the growing test requirements resulting from increased use of liquid-propellant space boosters, the center returned to testing large liquid storable and cryogenic-propellant rocket engines after a hiatus of nearly 20 years. We

played a key role in keeping the Titan IV, America's only expendable, heavy-lift launch vehicle, from being grounded by qualification testing a new Stage II engine nozzle and are currently testing the next-generation RL-10 engine. AEDC's newest rocket facility, J-6, significantly expands our capability to test the large and detonable solid rocket motors that will extend the life of the existing ICBM force through 2020.

AEDC is expanding its use of teaming arrangements with rocket developers, resulting in a greater range of services and increased responsiveness. For example, a teaming arrangement between AEDC, the Air Force Space and Missiles Systems Center, Lockheed Martin, Aerojet, TRW, Brown & Root, and a host of smaller contractors accomplished the complex facility preparations and test program for the Titan IV engine test program. Similarly, the first test program using

the new cryogenic propellant system also involved similar teamwork. In each case, the teaming arrangement allowed its members to contribute their expertise and resources to ensure a more comprehensive, faster test program to fit the customer's needs.

True to our vision of being the center of knowledge for simulated-altitude rocket testing, we completed a number of initiatives to improve the scope and quality of the products available to our users. These include: statistical analysis of aging trends in solid rocket motors, hosting the Minuteman Propulsion System Rocket Engine database, advances in liquid rocket engine health monitoring, and improved test information handling, storage, and retrieval.

AEDC is taking advantage of this period of growth and expanding horizons to continue as the test center of choice for simulated altitude rocket testing well into the next century.

Why Test at Altitude?

Upper-stage rocket motors and engines can behave and perform differently depending on their flight environment. Testing upper-stage rocket propulsion systems is accomplished by either ground test or flight test.

Usually, ground testing leads flight testing and then, once a system is operational, ground testing supplements flight testing. Typical rocket ground test programs include development, qualification, flight proofing, production quality assurance, aging and surveillance, and anomaly investigation.

Selecting the ideal method for a particular test is a trade off between cost, risk and desired outcome. At one end of the spectrum, ground testing upper-stage systems at ambient pressure and temperature conditions provides data at the

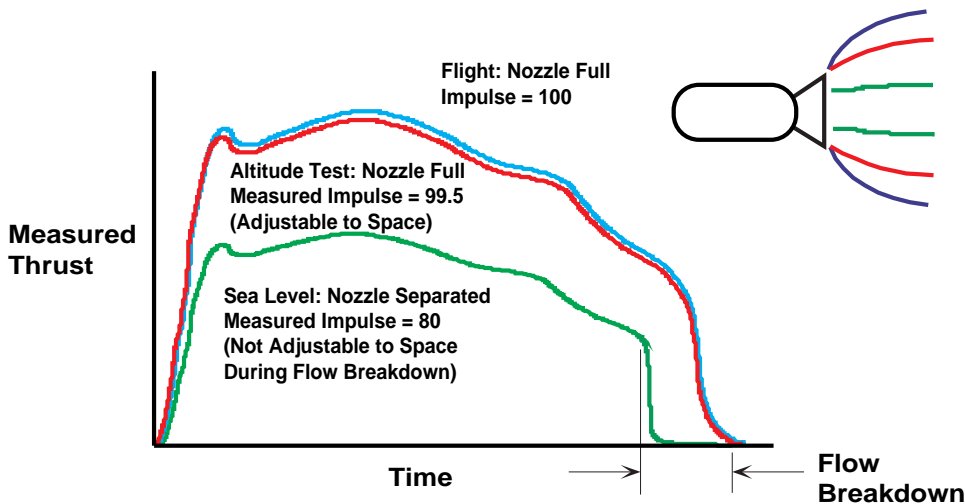
lowest cost. However, the test article must be altered and performs in an unrealistic environment, which can compromise test objectives.

Flight testing, which provides the most realistic conditions, is at the other end of the spectrum. The trade off is high cost, risk to the entire vehicle and payload, telemetry limitations in data quality and quantity, and the inability to recover the test article following the test for analysis. In the middle of the spectrum lies simulated altitude ground testing.

Ground testing upper stage rocket propulsion systems at simulated altitude pressure conditions accurately replicates their flight environment. Significant differences in system performance at simulated altitudes as opposed to ambient conditions include:

Benefits of Altitude Testing

- NO RISK TO FLIGHT VEHICLE
- LOWER COST
- BETTER INSTRUMENTATION
- CLOSE OBSERVATION
- RECOVERABLE CASE/ENGINE/NOZZLE
- REALISTIC IGNITION
- MORE ACCURATE IMPULSE
- BETTER FIDELITY FOR DURABILITY ASSESSMENT



Key Performance Objectives

1. High area-ratio nozzle behavior
2. System thrust and impulse
3. Heat transfer characteristics of both engine and vehicle base regions
4. Thrust vector control performance
5. Ignition start transients
6. Plume characteristics

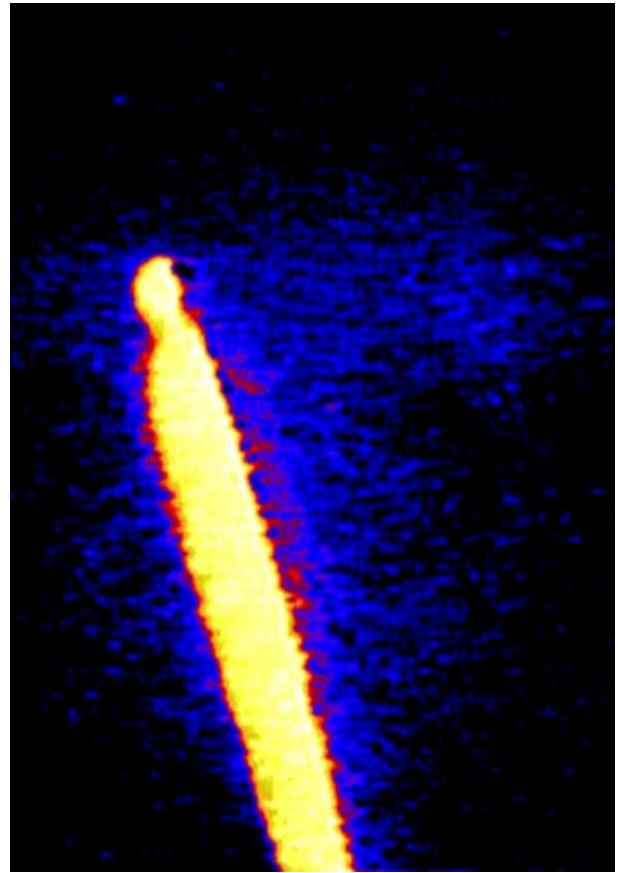
For example, upper stage propulsion systems are optimized for increased performance with large area-ratio nozzles. Simulated altitude testing for these systems is required to flow the nozzle “full,” which provides accurate thrust and specific impulse measurements.

Attempting to test at ambient (sea-level) conditions not only compromises engine performance data, but can jeopardize the structural integrity of the nozzle by imposing severe dynamic loads and thermal stresses from nozzle flow separation. Sea-level testing with truncated nozzles does not evaluate nozzle structural integrity and, furthermore, requires test data be adjusted to calculate full-nozzle and thrust vector control systems performance.

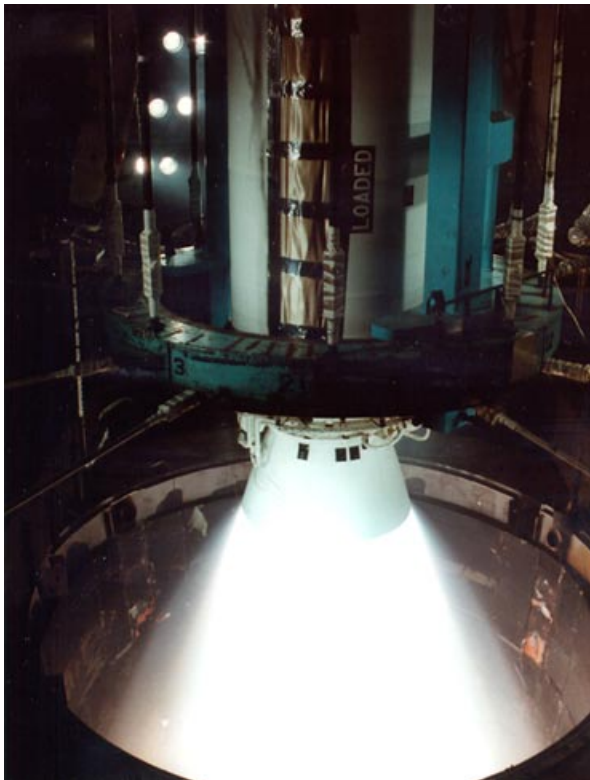
Advantages of ground testing under simulated altitude conditions include carefully-controlled test environments with extensive instrumentation and photographic coverage to determine the operability and performance of a test article. Ground testing can include an extensive array of sophisticated rocket diagnostic instruments obtainable only in a ground test configuration. State-of-the-art techniques such as wide band radiometric infrared and ultraviolet coverage, emission/absorption detection, laser-induced fluorescence plume surveys, and real-time radiography are just some of the typical applications frequently used.

Using a combined simulated-altitude ground test and flight test approach can mitigate program risk with reduced cost and greater understanding of true system performance.

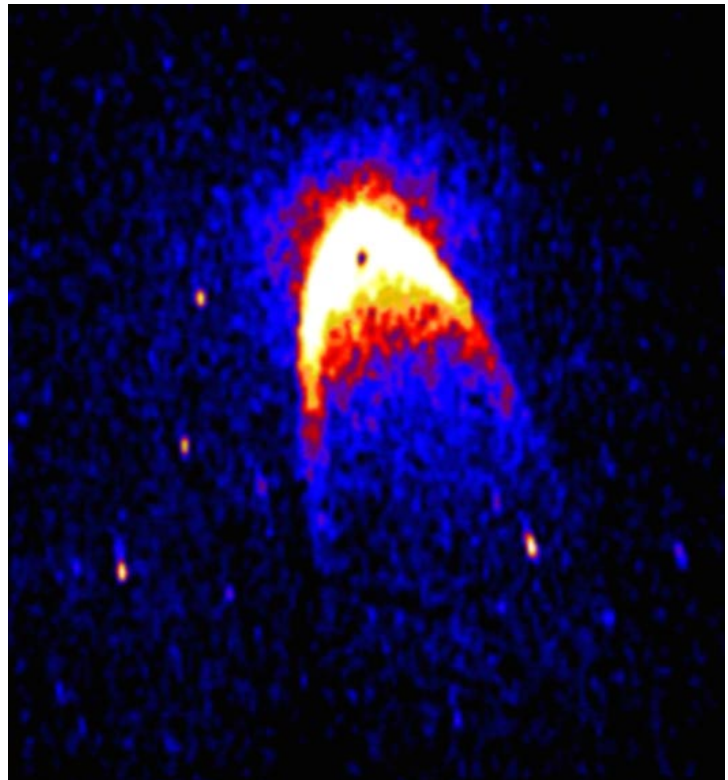
All three techniques have benefits, but the synergism of using them in a well balanced integrated test program yields multiple dividends over the system’s life cycle.



Flight rocket plume at low altitude.



Full-scale solid rocket plume at simulated high altitude in AEDC's J-4 test cell.



Flight rocket plume at high altitude.

Titan IV Stage II LR-91 Engine Test Program

The Titan IV Stage II LR-91 engine test program was one of the most ambitious and successful rocket test programs ever conducted at AEDC. America's heavy lift launch capability hit a major snag when an LR-91 engine failed a nozzle qualification test under sea-level conditions in July 1995.

Exactly eight months from authorization to proceed, AEDC had installed a new hypergolic propellant system, reactivated its J-4 large simulated-altitude test facility, and successfully tested an LR-91 engine for 274 seconds, a new record for altitude testing an engine of that size. Not only did the nation regain its heavy lift launch capability with qualification of a new quartz phenolic nozzle, but it was the first AEDC test of a large liquid engine in nearly 20 years. The record was to stand for only 28 days as AEDC fired another LR-91 engine for 300 seconds.

The Aerojet LR-91 engine produces approximately 106,000 pounds of thrust. It is a pump-fed engine burning the hypergolic propellants Aerozine 50 and nitrogen tetroxide. The Air Force Space and Missile Systems Center (SMC) selected AEDC to conduct the nozzle qualification tests due to its unique capability to test large liquid engines for long duration under simulated-altitude conditions. Due to the size and complexity of the task to complete the J-4 facility modifications, AEDC entered into a teaming arrangement with SMC, Lockheed Martin Astronautics, TRW, Brown and Root and a host of smaller companies in a joint cooperative effort.

In both tests, AEDC met 100 percent of primary and secondary test objectives using a wide array of diagnostic instrumentation to verify the nozzle material withstood the full 300 second burn and to collect

additional plume phenomenology and nozzle heating data. This instrumentation included high-speed video and movie cameras to verify nozzle structural integrity, infrared imaging to map nozzle thermal distributions and detect hot spots, and laser induced fluorescence to investigate propellant film cooling in the nozzle.

The Assistant Secretary of the Air Force for Acquisition, Arthur L. Money, expressed his appreciation in a letter to Gen. Henry Viccellio, then commander of Air Force Materiel

Command, "We needed a Herculean effort to support our critical operational launch commitments and once again your people delivered. The combined AFMC/contractor team pulled together to keep the Titan flying. Their outstanding work in bringing a 35-year-old facility back on-line, while simultaneously integrating new water handling and hypergolic fuel systems to support both the Titan and EELV programs represents a truly amazing effort."

A Titan IV second stage engine fires in AEDC's J-4 Rocket Test Cell.

Test Highlights
Rocket Propulsion

Programs

Pratt & Whitney RL-10B2 Test

AEDC recently completed three major “firsts” in testing Pratt & Whitney’s RL-10B2 engine, an entry in the Evolved Expendable Launch Vehicle Program.

This was the first use of AEDC’s new cryogenic propellant system and the first test of such a large nozzle extension under simulated altitude conditions, and the first demonstration of a two-test-per-week cycle time capability.

The Pratt & Whitney RL-10B2 is a liquid hydrogen/liquid oxygen fueled rocket engine producing a nominal thrust of 25,000 pounds. The test program included development and quali-

fication testing of RL-10B2 engines with the improved nozzle extension. Test requirements included 250 second burn times and approximately 100,000 foot simulated altitudes.

The engine uses a new extendible carbon/carbon nozzle extension with a nominal area ratio of 285 to 1 to obtain the required performance. The high area ratio and fragility of the light-weight nozzle required the low cell and back pressures attainable using the unique AEDC exhaust capability.

To assess the improved performance of the new nozzle extension, accurate engine thrust measurement was

a prime test objective. To satisfy this requirement, AEDC used a multi-component force thrust stand with a new in-place applied load calibration system.

The in-place calibration feature allows for a more accurate measurement by allowing for external “tare” forces inherent in cryogenic propellant feed systems connected to the engine.

Secondary test objectives included subjecting the engine to off-nominal conditions during start and steady-state operation and rapid relights as part of the development and qualification programs.



An AEDC engineer inspects the Pathfinder engine tested in the center’s J-4 Rocket Test Cell. Following a \$9.7 million reconfiguration and reactivation program, the center resumed testing of cryogenic liquid-propellant rocket engines.

An RL-10 engine with a nozzle extension is tested to verify performance.

Aging and Surveillance Test Programs

AEDC has actively supported Aging and Surveillance (A&S) testing of Minuteman and Peacekeeper ICBM propulsion systems at simulated altitude conditions since the late 1960s.

Until the activation of the J-6 Test Facility, most of this testing occurred in the J-5 Test Facility; however due to its size, the Peacekeeper Stage II was tested vertically in the J-4 Test Facility.

Activating J-6 allowed the consolidation of all solid rocket motor testing in one facility. J-6 is ideally suited for these tests due to its large size and capability to test detonable motors under simulated-altitude conditions.

From its activation, through September 1997 five Peacekeeper and seventeen Minuteman motors were tested in J-6 with 100 percent of the test objectives accomplished on each test.

The Ogden Air Logistics Center (OGDEN-ALC), Hill AFB, Utah, manages the ICBM A&S Program. Their objectives are to identify any age-related degradation in motor or component performance and project the service life of the ICBM fleet.

AEDC supports OGDEN-ALC by testing the solid upper stage motors at simulated altitude conditions to provide the data necessary to accurately identify aging trends in system performance.

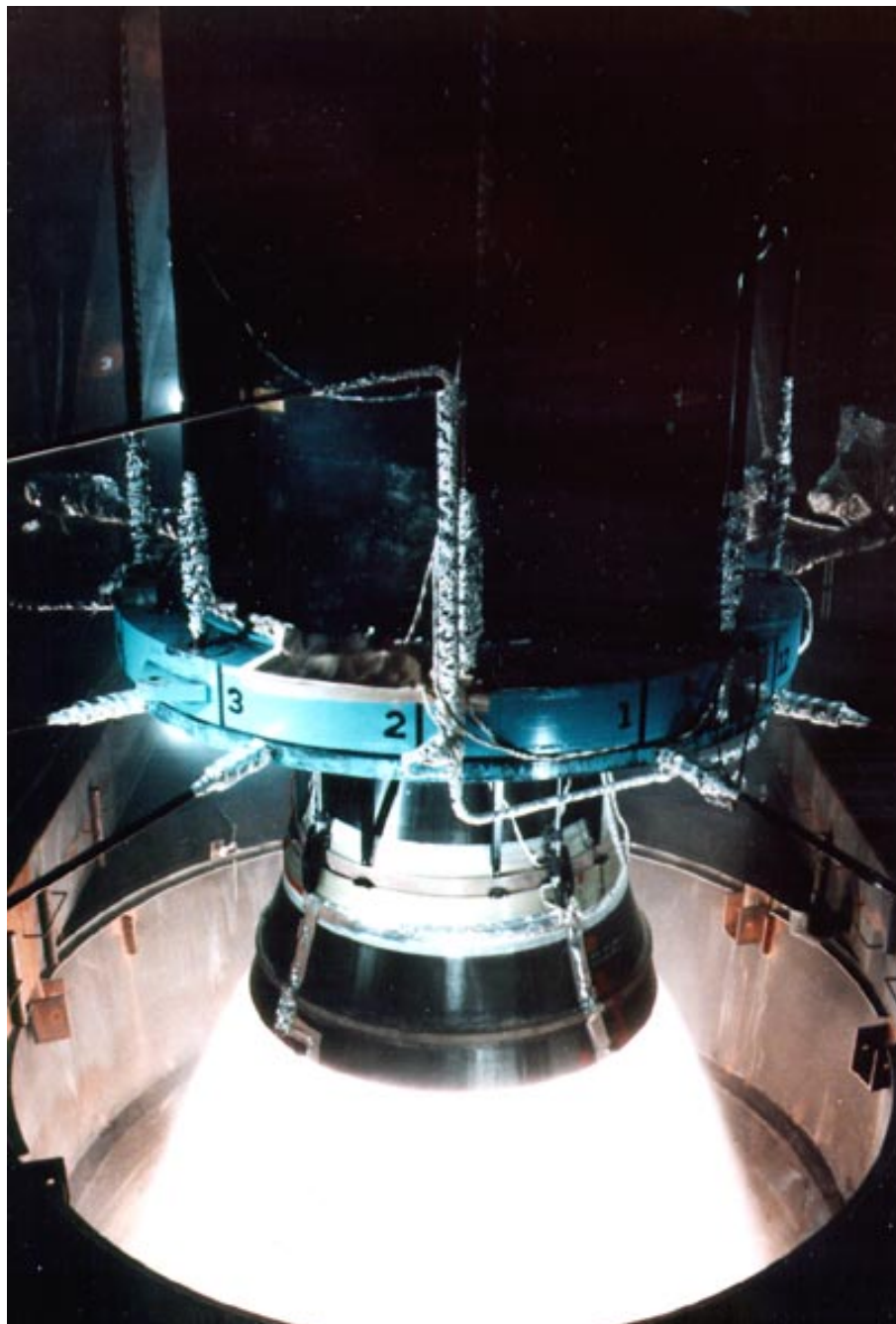
OGDEN-ALC selects test motors to support the A&S effort from the deployed operational system. Therefore, the motors being tested have been exposed to the operational (silo) environment and represent the most aged assets in the field.

AEDC also supports the A&S Minuteman and Peacekeeper post-boost propulsion systems testing. These are self-contained, prepackaged liquid bipropellant propulsion

systems tested at simulated altitude conditions in the J-3 Test Facility. The objectives of these tests are the same as for the solid stages, to identify any age-related degradation in system performance and project the service life of the system.

In addition to simply providing test services, AEDC brings a suite of tools to

help evaluate motor performance. These include database management and statistical analysis to identify aging trends as well as test tools including acoustic sensing to determine propellant burn rate regression, real-time radiography to assess motor internal status, and a host of computational models to aid in performance evaluation.



A 300,000-pound thrust Peacekeeper ICBM Stage II solid rocket motor is fired in J-4, the nation's largest altitude simulation rocket test cell.

AEDC Supports Minuteman III Propulsion Replacement Program (PRP)

The Minuteman III Propulsion Replacement Program (PRP), managed by the Ogden Air Logistics Center (OGDEN-ALC), will extend the service life of the three solid propellant stages through 2020. The PRP is composed of two phases: Technology Insertion and Remanufacture.

During Technology Insertion, changes are being incorporated into existing motor designs and processes to comply with environmental regulations and to correct known hardware problems. These design and process changes are demonstrated/verified by full-scale Change Verification Motor (CVM) tests and qualified by Qualification Motor (QM) tests. Production Quality Assurance (PQA) motor tests will verify specification compliance during the remanufacture phase.

The CVM tests simulate the operating environment to evaluate the performance of the system and obtain data comparable to historical data. For these reasons, the second and third stage motors are tested at AEDC's J-6 Large Rocket Test Facility which allows the motors to be tested at a simulated altitude of up to 100,000 feet while gathering the necessary data to evaluate the component changes and overall system performance.

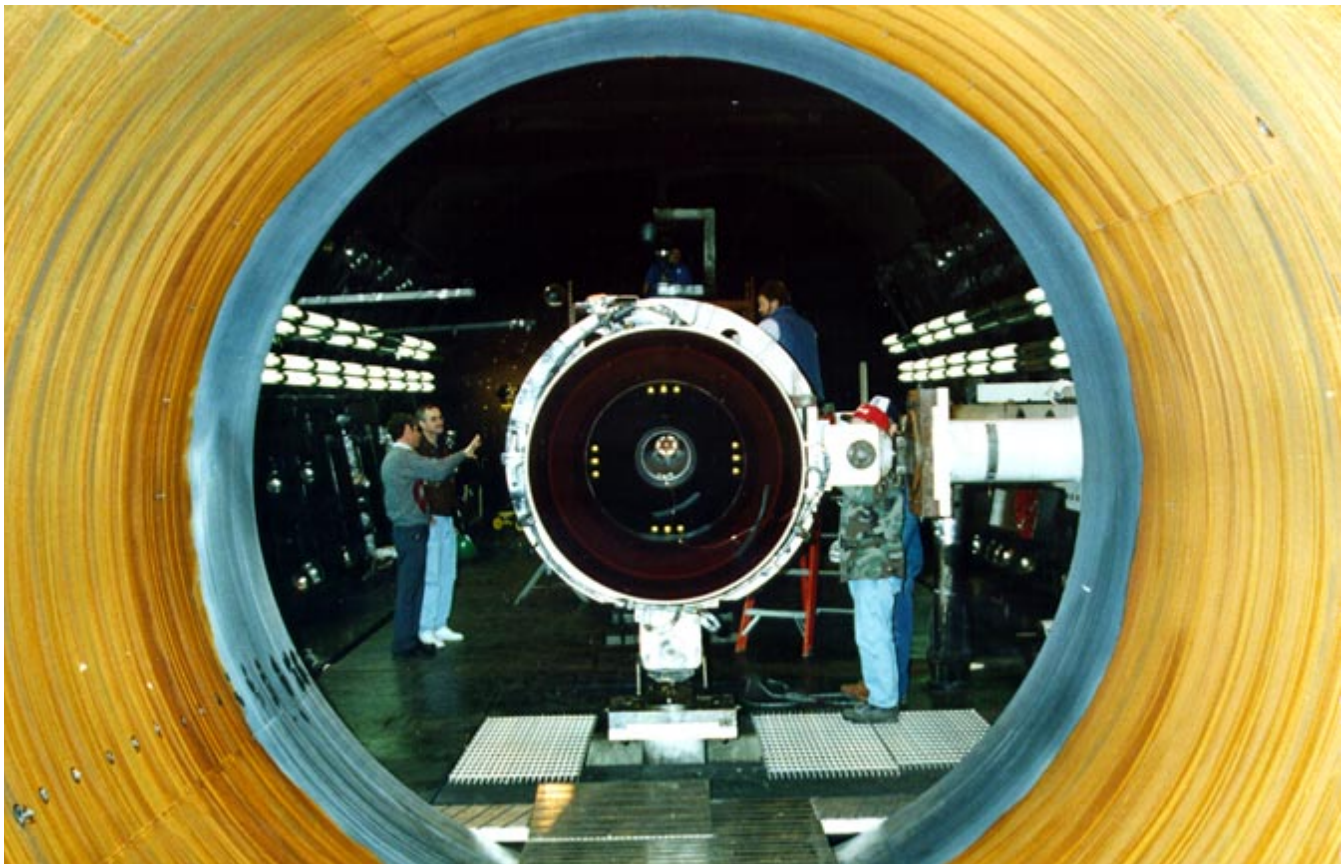
In fiscal year 1996 there were two Stage II CVM tests. In fiscal 97 there were three stage II CVM tests and three stage III CVM tests. The CVM testing is planned to be completed in fiscal 98 with four Stage II and three Stage III tests. The first QM testing will begin in fiscal 99 with three Stage

II and four Stage III tests and then be completed in fiscal year 2000 with three Stage II and four Stage III tests.

Test data is archived using AEDC's Test Project Archiving System, TPAS, system in a CD-ROM format. This allows all test plans, procedures, data, videos, and related documentation to be stored in a single location for easy retrieval.

To assist in maximizing useful information from these tests, AEDC has employed several advanced diagnostic tools.

These include high-speed video, acoustic sensing of propellant burn rates, and the use of real-time radiography (RTR) to visualize internal phenomena during the motor firing.



A Minuteman III rocket motor is installed in the J-6 Large Rocket Test Facility.

Test Highlights
Rocket Propulsion

AEDC's Altitude Rocket Propulsion Test Facilities

AEDC has unique test capabilities for testing rocket systems with high performance, high area-ratio nozzles, and those requiring altitude start and restart, stage separation, and solid rocket motor spin testing.

The unique capabilities come from the physical size and configuration of our test facilities and their connection to the Engine Test Facility (ETF) exhaust plant. These facilities are the largest of their kind in the world and provide the only altitude test capability for medium to large liquid and solid rocket propulsion systems. AEDC facilities are characterized by:

The connection to the AEDC ETF Exhaust Plant, combined with the use of a unique close-coupled annular steam ejector, provides optimal means of attenuating potentially damaging facility pressure transients that occur during engine ignition and shutdown.

This unique configuration provides for the only safe test capability of rocket propulsion systems utilizing fragile, high performance (high area-ratio) nozzles.

Connection to the exhaust plant also allows for extended run times at altitude conditions required for many propulsion systems used in orbital transfer operations.

To better understand this, consider AEDC's simulated altitude rocket test facility's configuration and operation. First, the test cell is a cylindrical chamber that contains the test article at the required test conditions of pressure and temperature. In the cell, static restraint of the test article is provided by a full six-component force measurement system with an inplace calibration system for increased measurement accuracy. Maintaining the required test conditions requires the constant removal of the rocket's exhaust products as

(continued on next page)

Key Features

- Environmental cleanliness through exhaust handling measures
- Exhaust plant and close-coupled steam ejectors to simulate altitude conditions
- Accurate six-component thrust measurement
- Instrumentation and control systems

Complete test support infrastructure including:

- Fabrication and machine shops
- Clean rooms
- Radiographic inspection facility
- Instrumentation calibration labs
- Secure storage with explosive site approval
- Large high-speed computer data acquisition and processing systems
- Compatibility with an extensive array of diagnostic tools



J-6 Horizontal Rocket Propulsion Development Simulated Altitude Facility.

Test Highlights
Rocket Propulsion

Facility Summary

The ETF exhaust plant removes the exhaust gas products from the test facility. This function provides for a relatively low simulated altitude pressure. The exhaust plant performance is augmented and extended by using a diffuser system located immediately behind and in close proximity to all the rocket engine nozzle exit.

During engine operation the diffuser aspirates the test cell gases in a complicated flow entrainment and mixing process while exchanging kinetic energy for pressure by flow deceleration. This is even further enhanced by a steam ejector-diffuser immediately downstream of the engine diffuser exit plane. Using an annular type steam ejector located close to the rocket engine nozzle exit is an optimum configuration unique to AEDC's rocket test facilities.

The steam ejector-diffuser system provides two important functions. Before rocket engine ignition, the steam ejector-diffuser operates alone and helps establish the proper test cell pressure for the test objectives.

After rocket engine ignition, test cell pumping responsibility is transferred to the rocket engine ejector-diffuser system allowing the steam ejector to be "throttled back." Upon engine shutdown, the process is reversed and a tran-

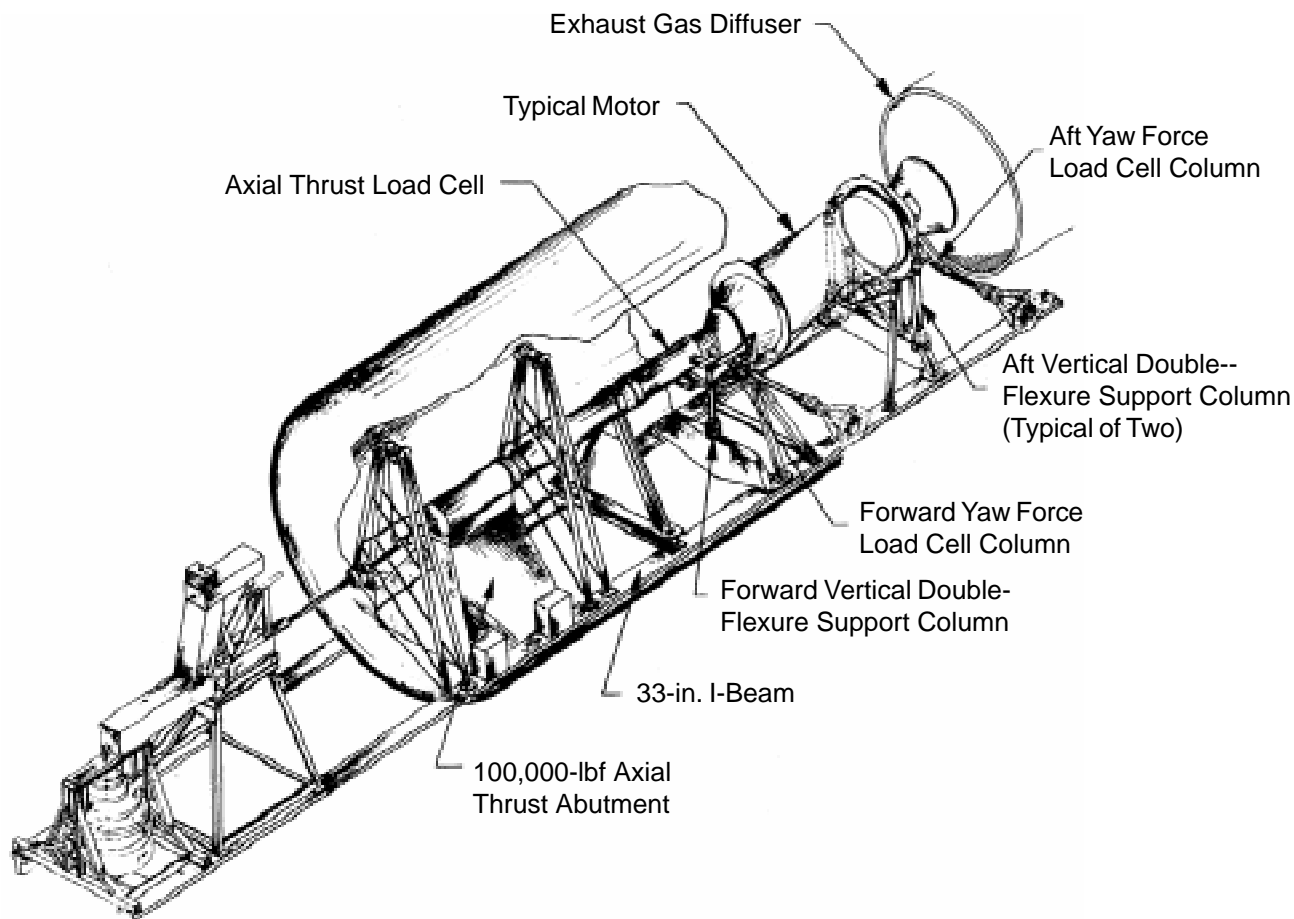
sition in the pumping and pressure recovery responsibility is handed back to the steam ejector-diffuser system alone.

Operating in this manner, the steam ejector-diffuser system performs like a quick response pneumatic check valve, that minimizes the test cell pressure transients during engine ignition and shutdown. The steam ejector isolates the test cell from the spray chamber and allows a controlled pressure equalization process between the two chambers.

Rocket test operations require the removal of hazardous exhaust products from the flow before reaching the exhaust plant. The importance of this exhaust cleaning process is becoming more evident as environmental regulations become more stringent. The cleaning process involves scrubbing the exhaust with large amounts of cooling water which removes all the condensable species from the rocket exhaust. This cooling water treatment also greatly aids exhaust gas pumping by removing the large quantity of water vapor produced by the steam ejector.

The environmental treatment is concluded when the cooling water is released in an approved, passive neutralization process back to the AEDC reservoir.

Multicomponent Thrust Measuring System



Rocket Development Test Cell J-3

- *Vertical orientation*
- *125,000 ft. simulated altitude*
- *17 ft. diameter x 40 ft. high*
- *200,000 lb. max. thrust*
- *80,000 data samples/second (aggregate)*

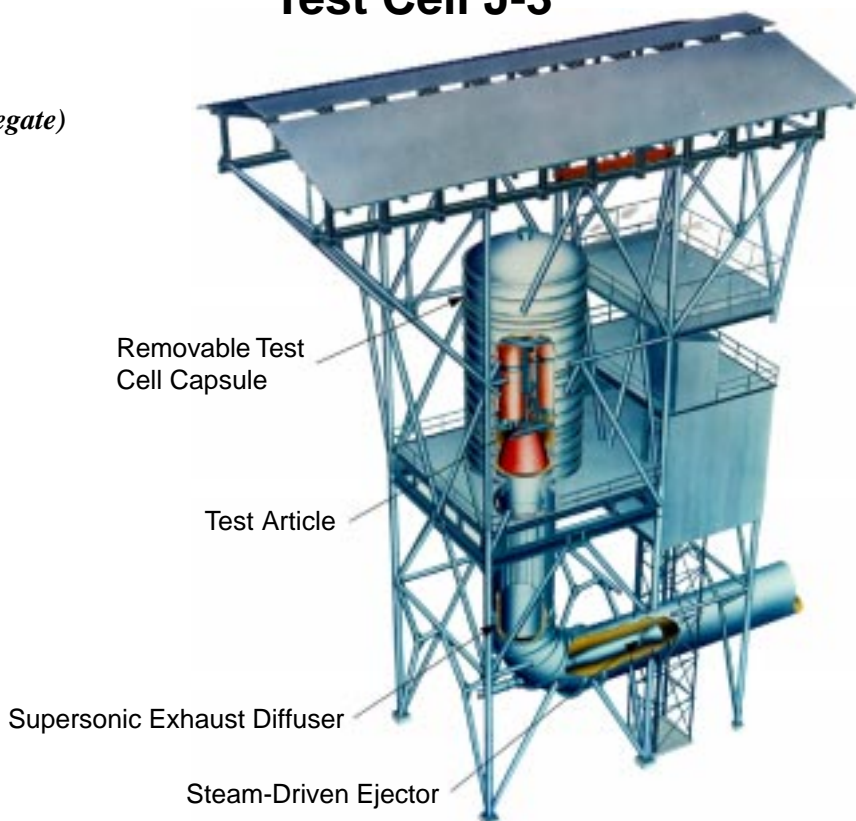
Rocket Development Test Cell J-3 is a vertical test cell designed to test engines with up to 200,000 pounds thrust at a simulated altitude up to 125,000 feet. However, current safety restrictions limit testing to engines with less than 4,000 pounds of class 1.3 propellant. In addition to simulated altitude control, J-3 is equipped with liquid nitrogen-cooled panels for simulating low-temperature (20° to 130°F) environments in addition to low pressures. The J-3 test cell capsule has an internal diameter of 17 feet and a height of 40 feet.

The facility is capable of testing stand-alone engines and fully-integrated liquid or solid stages, such as ICBM post-boost stages. A recent improvement to J-3 is the addition of a storable propellant feed system which allows testing of small storable engines with up to 1,000 pounds per foot of thrust.

Unique test capabilities include: Extremely long duration altitude (mission duty cycle) tests; tests of high-area-ratio nozzles (exit diameters up to 100 inches); and altitude performance, ignition performance, nozzle development, stage separation, heat transfer, vibration, dynamics, failure analysis (propellant extinguished), and post test heat-soak testing.

Some of the engines that have been tested in J-3 are the Titan Improved Transtage, AJ10-137 (Apollo Service Module), XLR-91 (Titan), Inertial Upper Stage, and Minuteman, Peacekeeper, and Small ICBM post-boost propulsion systems.

Test Cell J-3



The rocket motor for the Apollo Service Module is shown being installed in rocket test cell J-3.

Rocket Development Test Cell J-4

- *Vertical orientation*
- *100,000 feet simulated altitude*
- *48 feet diameter x 125 feet high*
- *1,500,000 pound max thrust*
- *250,000 data samples/second (aggregate)*

Rocket Development Test Cell J-4 is a vertical test cell designed for testing large liquid-propellant engines or solid-propellant rocket motors and entire propulsion stage systems at simulated altitudes up to 100,000 feet. The test facility has a design limit of 1,500,000 pounds of axial force; however, support equipment in its current configuration limits the measurement capability to 500,000 pounds of axial force and 50,000 pounds of side force.

The test cell is equipped with a temperature-conditioning system designed to maintain the test article at a prescribed temperature from 50° to 110°F ($\pm 5^\circ\text{F}$). The facility is uniquely suited for vehicle integration tests because of its large test cell volume. The test cell has a 48-foot basic diameter with an available capsule height of 82-feet which can be extended to a maximum height of 125 feet by the addition of 43-foot spools. The test complex also includes a large volume dehumidification chamber (100 feet in diameter by 250 feet deep).

Test capabilities of the J-4 test cell facility include:

- long duration altitude (mission duty cycle) testing
- testing of high-area-ratio nozzles
- simulated altitude performance testing
- ignition performance testing
- nozzle development testing
- stage separation tests
- heat transfer effects and post-test heat soak testing
- vibration and dynamics testing
- failure analysis (propellant extinguished) testing
- vertical spin testing

AEDC has recently installed a hypergolic (AZ50/NTO) propellant system which was used to test the Titan IV LR-91 engine and a cryogenic (LOX/LH2) propellant system.

Due to the large size of the facility, J-4 is uniquely suited to accommodate an extensive suite of state-of-the-art diagnostic instrumentation. AEDC has demonstrated these diagnostic tools, which include laser fluorescence, infrared and ultraviolet imagery, high-speed video, and real-time radiography, to verify system performance and structural integrity and characterize plume signature phenomenology and flowfields.

AEDC has tested a number of liquid-propellant engines in the J-4 cell, including the LR-91 (Titan II/III), LR-87 (Titan IIIC), J2 (Apollo/Saturn), J2S (Post-Apollo), RL-10, and TR-201. Solid-propellant rocket motors tested in J-4 include the Peacekeeper Stage II, Minuteman Stages II and III, Trident Stage III, Super BATES, Small ICBM Stage II, and STAR 27 and 13A motors.



Rocket Development Test Cell J-4



A storable liquid rocket engine firing in support of plume characterization experiments in the J-4 Vertical Altitude Simulation Chamber.

Rocket Development Test Cell J-5

- *Horizontal orientation*
- *100,000 feet simulated altitude*
- *16 feet diameter x 50 feet long*
- *125,000 pounds max thrust*
- *250 data samples/second (aggregate)*

Rocket Development Test Cell J-5 is a horizontal test complex designed primarily for static testing of solid-propellant rocket motors with up to 125,000 pounds per foot thrust at simulated altitude conditions of up to 100,000 feet during firings and 140,000 feet for static conditions.

A test cell auxiliary pumping system is available for increasing test cell altitude and/or for removal of gases liberated in the tests cell capsule by gas generators, thrust vector control subsystems, and thrust termination devices.

The test cell is 16 feet in diameter and 50 feet long, and is equipped with a temperature-conditioning system designed to maintain the test article at a prescribed temperature within a range of 15° to 110°F ($\pm 5^\circ\text{F}$).

A multicomponent force-measuring system provides precision ballistic data capability in the range from 0- to 127,000 pounds per foot axial, 22,000 pounds per foot yaw, and 75,000 pounds per foot pitch force. The axial thrust abutment and load train are rated to 300,000 pounds per foot.

The remotely controlled binary deadweight axial calibrator used with load cells within its range can select any force level from 0 to 127,000 pounds per foot in incre-

ments of 1,000 pounds per foot. Pitch-, yaw-, and roll-force columns are equipped with laboratory-calibrated load cells. The test cell can incorporate a flexure-mounted spin fixture to test motors under the combined effects of simulated altitude and rotational spin (up to 250 rpm, depending on motor weight).

Test capabilities of the J-5 test facility include:

- long-duration altitude tests
- launch pressure profile tests
- testing of high-area-ratio nozzles
- altitude performance tests
- ignition performance tests
- spin testing
- nozzle development testing
- stage separation testing
- heat transfer and posttest heat soak testing
- vibration and dynamics testing
- failure analysis (propellant extinguished) testing

Solid-propellant rocket motors tested in J-5 include Scout, Castor Stages II and IIA, Minuteman Stages II and III, Athena Retro, Titan III subscale, five- and seven-segment stages, Poseidon Stage II, inertial Upper Stage (IUS), Improved Performance Space Motor (IPSM), Peacekeeper Stage III, PAM-DII, Intelsat IV, Small ICBM Stages II and III, SDI ORBUS, STAR 37 and 63, and solid propellant gas generators, as well as various demonstration motors.



Aerial of Rocket Development Test Cell J-5.



J-5 support space systems payload systems such as (IUS, PAM D-11 and STAR).



Minuteman Stage III in J-5

Large Rocket Development Test Cell J-6

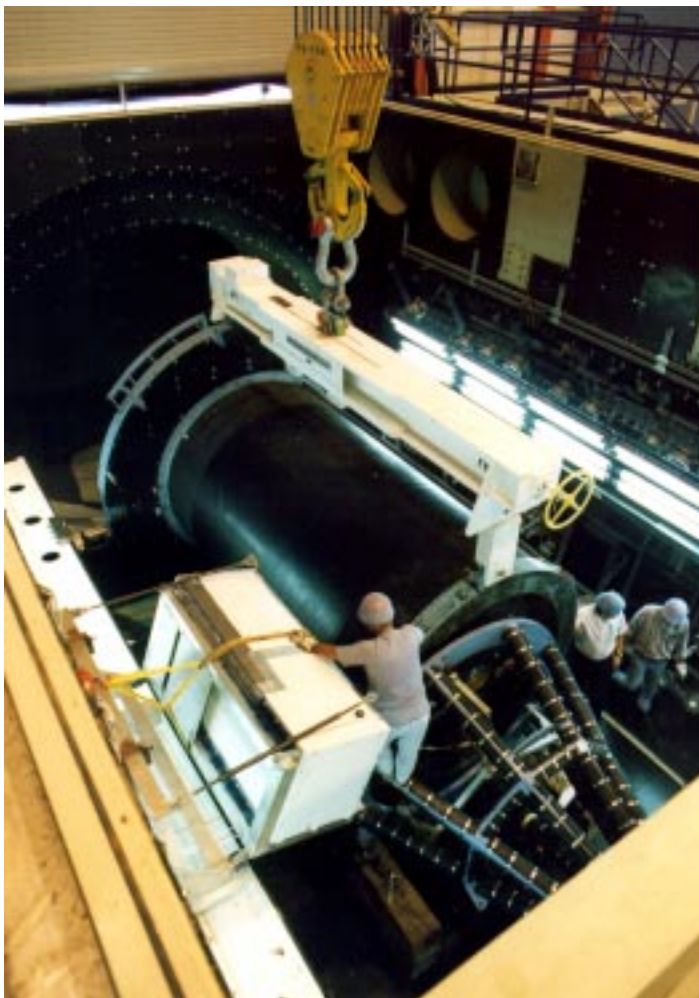


- *Horizontal orientation*
- *100,000 feet simulated altitude*
- *26 feet diameter x 62 feet long*
- *500,000 pound max thrust*
- *250,000 data samples/second (aggregate)*

J-6 is designed to test large detonable solid-propellant rocket motors with up to 80,000 lbm of class 1.1 propellant.

J-6 is located more than one-half mile away from other AEDC facilities to eliminate the potential for damage in the event of an explosion. The cell can accommodate testing motors with up to 500,000 pounds thrust at simulated altitudes of 100,000 feet. The test

View from the J-6 Dehumidification Chamber of the J-6 Test Cell Building and Interchangeable Exhaust Diffusers.



A Peacekeeper Stage II is loaded into the J-6 test cell.

capsule is a cylindrical section 26 feet in diameter and 62 feet long. The temperature-conditioning system can maintain the test cell air temperature at a prescribed temperature within the range of 15° to 110°F ($\pm 5^\circ\text{F}$) from motor installation until prefire pumpdown at altitude conditions.

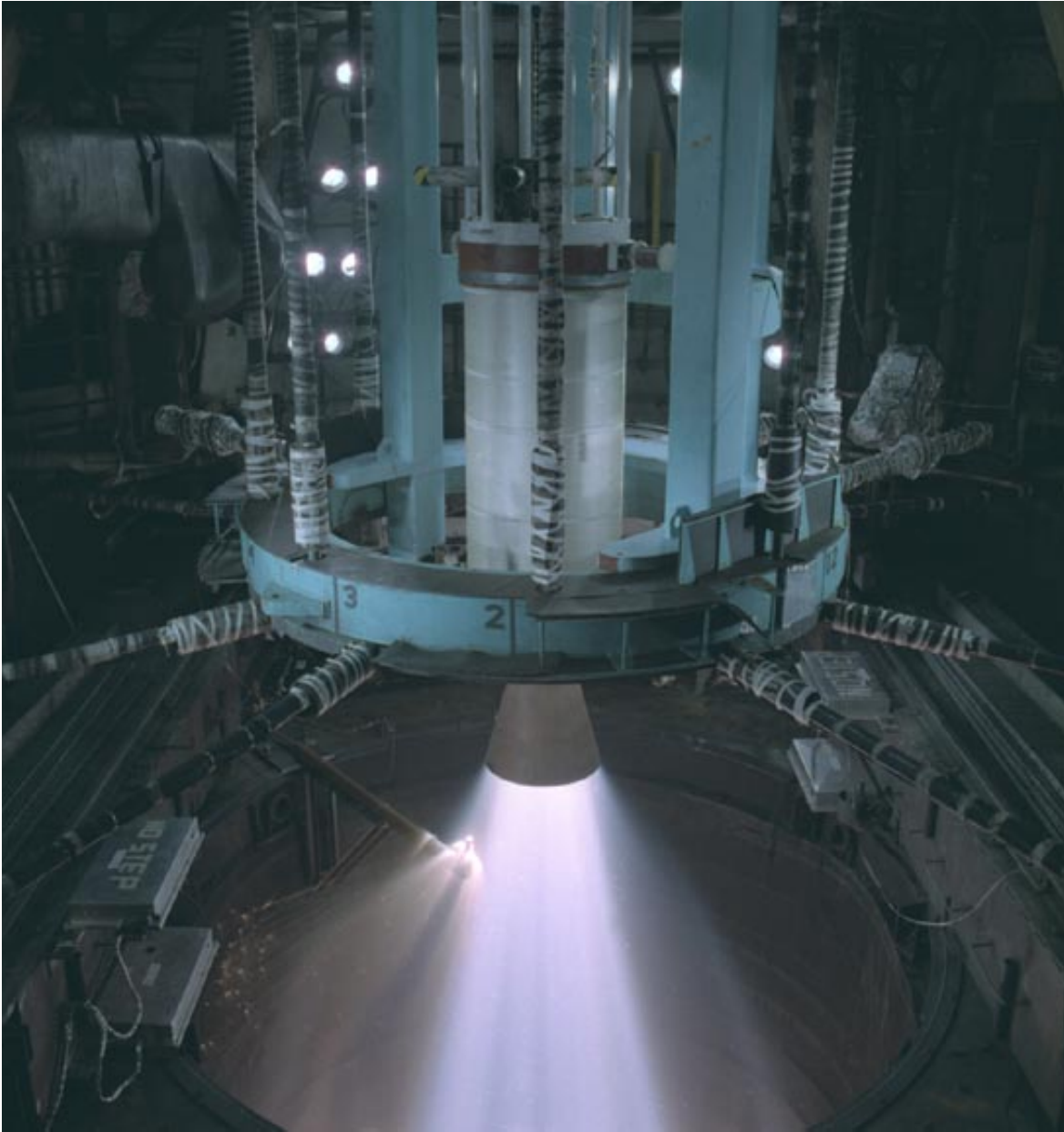
In addition, the dehumidification chamber can be used as a 250-foot-diameter by 100-foot-high concrete vacuum bottle, and would be ideally suited to support special testing associated with space vehicles and rocket plume studies.

The cell was designed for use with many state-of-the-art diagnostic tools including acoustic sensing, real-time radiography, laser positioning systems, infrared and ultraviolet imaging, and high-speed video.

Test capabilities of J-6 include:

- long-duration altitude tests
- testing of high-area-ratio nozzles
- altitude performance tests
- ignition performance tests
- spin testing
- nozzle development testing
- stage separation testing
- heat transfer and posttest heat soak testing
- vibration and dynamics testing
- failure analysis (propellant extinguished)

J-6 has been used to test Minuteman Stages II and III and Peacekeeper Stages II and III. It can be used to test many motors with either large quantities of propellant or with detonable propellants.



A Super Bates solid rocket motor being fired in J-4.

Successful acquisition of the desired information from simulated flight testing at AEDC is supporting plume characterization studies by an ongoing analysis and evaluation (A&E) capability development and demonstration program and a complementary technology development program.

Both of these programs are focused on equipping AEDC to better meet customer needs by identifying new or future test and evaluation requirements and developing the capabilities required to meet those needs.

The A&E program is primarily involved with identifying, developing and demonstrating new tools and techniques required to analyze test data

and evaluate the performance of the test article. The technology program is focused on establishing enabling technologies to support the development and demonstration of new test instrumentation, advanced diagnostic techniques, state-of-the-art computational and modeling capabilities, and advanced testing techniques, in addition to identifying requirements for and supporting the design of new test facilities.

The A&E and Technology staffs at AEDC represent a broad range of technical expertise and professional experience which can be used to assist in addressing specific program needs. Advanced diagnostics and modeling,

(continued on next page)

simulation and analysis are examples of capabilities that can significantly enhance the value of simulated altitude testing at AEDC.

Advanced Diagnostics

Advanced diagnostics techniques at AEDC encompass a variety of applications such as advanced propulsion diagnostics, real-time radiography and acoustic sensor measurements.

The personnel who perform these operations are highly skilled, dedicated team members who represent AEDC on important advisory committees including NATO-AGARD, AIAA, JANNAF, and various Air Force and DoD steering committees.

Advanced propulsion diagnostics capabilities at AEDC consist of staff and electro-optical instrumentation devoted to the measuring of radiative signatures, exhaust gas pressure and temperature profiles, hot parts temperatures, species concentrations, flow-field velocities and aerosol properties in two-phase flows.

AEDC also maintains a large body of engineering codes and knowledgeable personnel who are accustomed to helping our customers solve difficult problems. These involve real-gas propulsive flows with chemistry, spray combustion, two-phase flows, molecular spectroscopy, and radiative heat transfer.

The instrumentation spans the spectral range from the vacuum ultraviolet below 200 nm to the far-infrared beyond 15 microns, and includes lasers, spectrometers, radiometers and cameras.

The latter includes state-of-the-art infrared array cameras, unique ultraviolet cameras, gated image intensifier cameras and high-speed (6,000 frames per second) cameras.

Modeling, Simulation and Analysis

AEDC maintains an extensive library of state-of-the-art computer models applicable to support all areas of liquid and solid rocket testing.

Government standard computer programs that predict the spatial flowfield properties and the resulting steady-state thrust chamber performance (thrust, specific impulse, etc.) including quantification of inherent rocket performance loss mechanisms are an integral part of the computational library. The thrust chamber models supported include the latest versions of the Viscous Interactive Performance Evaluation Routine (VIPER), Two Dimensional Kinetic (TDK) computer program, the Standard Performance Program (SPP), and the Generalized Implicit Flow Solver (GIFS).

Interpreting nonintrusive measurements relies on the dependence of measured radiometric quantities (emission and transmission) to static

temperature, static pressure, velocity, and the chemical species concentration present in the flowfield region of interest.

Government standard radiative transfer computer models for particle-laden, propulsion-generated exhausts are included in the computer model library. These include the Standard Infrared Radiation Model (SIRRM) and the Standard Ultraviolet Radiation Code (SPURC).

These models encompass the spectral regime extending through the ultraviolet, visible and infrared wavelengths, ranging from 0.2 - 25 microns. These models can also be applied to simulate the emitted signature of the propulsion exhaust. This information is used to assess the vulnerability of the propulsion system to threat sensors.



Boundary-layer pressure measurements on a small liquid-propellant rocket engine.

Hypergolic Liquid Propellant Supply Systems

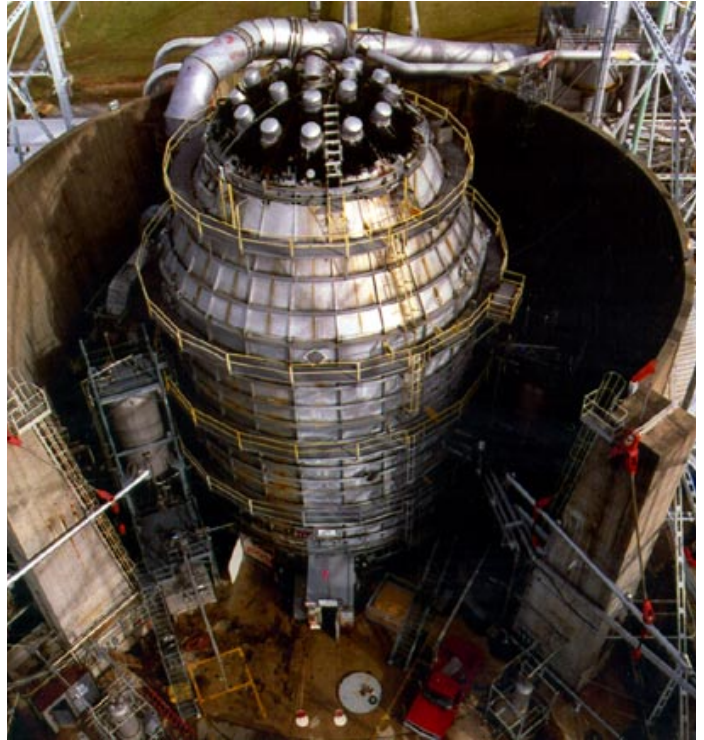
The Titan IV LR-91 engine uses storable, hypergolic liquid rocket propellants. The fuel (Aerozine-50) is nominally a 50-50 weight mixture of hydrazine and unsymmetrical dimethylhydrazine (UDMH), and the oxidizer is nitrogen tetroxide (N_2O_4). The hypergolic property relates to the ability to spontaneously ignite upon physical contact between the fuel and oxidizer.

The propellant system design consists of storage/run tanks and associated support structures, transport piping, safety spill pans, vent and purge provisions, and explosion proof electrical systems. A vacuum aspiration system was incorporated to remove residual propellant and vapors. Vapors were treated by the use of a scrubber system for the fuel and a flare stack for the oxidizer. The design also includes a propellant temperature conditioning system capable of maintaining a stable propellant temperature of 65 ± 5 deg Fahrenheit ($^{\circ}\text{F}$). Due to the toxic nature of these propellants, a state-of-the-art leak detection and alarm system accommodates the propellant system along with a local weather monitoring station to support propellant transfer and test operations.

The fuel and oxidizer system consists of a 7,000-gallon stainless steel tank located as close to the cell wall as possible to ensure the shortest pipe runs, and is designed to be filled from commercial tankers.



The bottom of J-4 test cell is 20 stories below ground



Bird's eye view of J-4 test cell.

Water Supply Augmentation

Cooling water flows are required in the J-4 spray chamber to cool and condense water vapor from the steam ejector and rocket engine exhaust flows before entering the ETF exhaust plant. Cooling water is also required to protect the steam ejector diffuser and exhaust flow deflector plate from the high-temperature impinging rocket exhaust gases, and to vaporize the liquid nitrogen (LN_2) used to render the exhaust gases inert.

Due to the specified extended firing time of the LR-91 engine (maximum duration of 300 second), additional cooling water capacity was required. The total amount required for a full-duration test was 2.27 million gallons.

The water augmentation effort consisted of constructing an additional 1.2 million gallon ground level water tank and piping it to the deflector plate and spray chamber supply line which was already fed by an existing 1.5 million gallon ground-level tank.

Additionally, the engine and steam ejector diffuser cooling line supplied by the existing elevated tank was tied to the underground 72-in diameter J-6 water feed line fed by the base water pumping system.

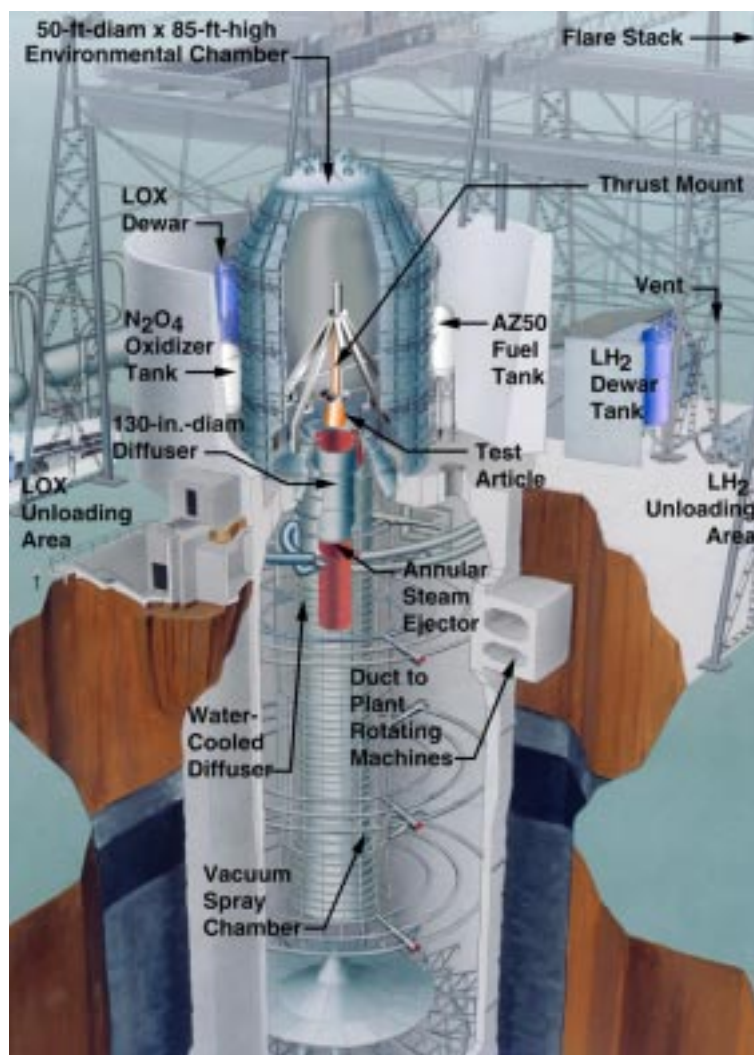
Modifications for Cryogenic Liquid Propellant Testing

Responding to inquiries for cryogenic liquid-propellant rocket engine testing, AEDC decided in 1993 to reactivate J-4 following a three year stand-down period and return it to a liquid propellant test configuration.

AEDC began design of a state-of-the-art cryogenic propellant system that would support testing of projected upper stage systems. Lacking specific engine and test criteria, AEDC used a “generic” turbopump-fed liquid rocket engine to set a design baseline capable of handling a nominal engine of 22,000-lbf thrust as a larger engine of 35,000-lbf thrust with mission length routines.

In March 1995, the Evolved Expendable Launch Vehicle (EELV) Systems Program Office selected J-4 as the test facility best suited for their upper-stage test support requirements and provided funding to complete the J-4 cryogenic propellant system upgrade with a scheduled IOC in July 1996.

Using these “generic” engine performance parameters, the cryogenic propellant supply and feed system was sized to accommodate 10,000 gallons of liquid hydrogen (LH₂) and 4,000 gallons of liquid oxygen (LO₂). State-of-the-art vacuum-jacketed storage vessels and run lines were designed and constructed. A graphical depiction of both the cryogenic and hypergolic propellant systems showing their relative locations at J-4 is presented in the top photograph. A discussion of the hypergolic system is given in the following sections.



Cutaway of J-4 with interchangeable diffuser insert.

Engine Diffuser Insert

The existing J-4 rocket diffuser system was optimized to test the Peacekeeper Stage II solid rocket motor which produces about 3 times the nominal exhaust mass flow of the LR-91 engine. The Peacekeeper diffuser was sized with an exhaust inlet diameter of 180-inch that transitioned to a throat diameter of approximately 130-inch diameter. With the test requirements calling for an LR-91 engine burn time of 300 seconds, an analysis of the existing J-4 diffuser was performed to assess its performance. This analysis showed that the existing diffuser would adequately maintain the required test cell pressure, but would break-down before the end of the 300-sec burn time due to its large exit diameter. Therefore, a new diffuser insert needed to be designed and built.

The new diffuser insert is a second throat configuration fabricated in three sections from PanlCoil®. The first two sections make up the diffuser's conical entrance. The entrance has a 130-in inlet diameter that tapers down to a 90-inch outlet diameter. The remaining component is a 90-inch diameter straight cylindrical section. Overall length of the insert is 486 inches.

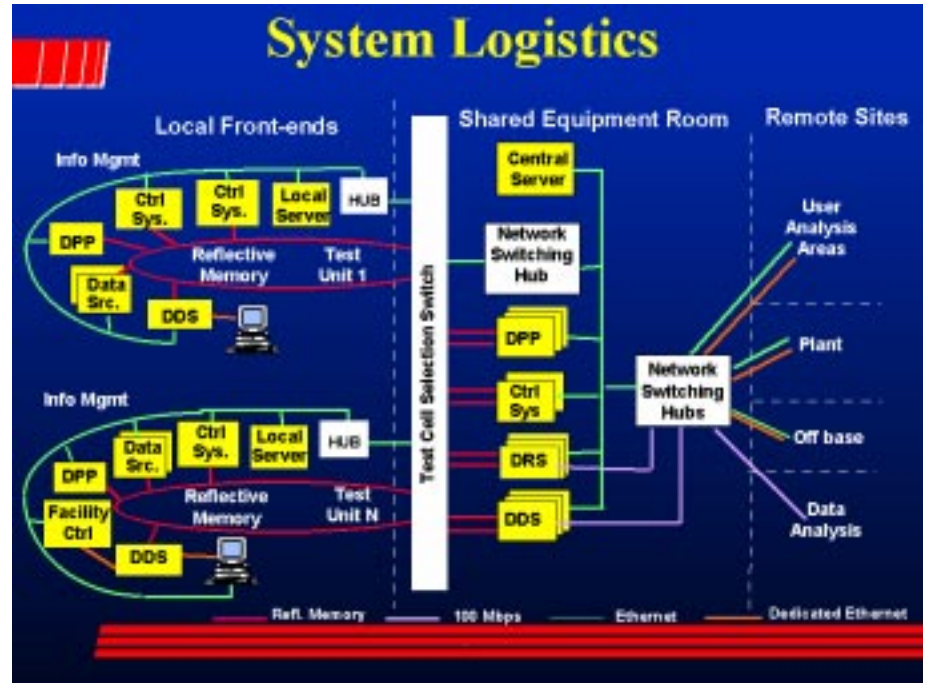
ETF Data Acquisition and Processing System

To support customer-requested enhancements to the rocket test units data processing capabilities, AEDC is initiating the EDAPS (Engine Test Facility Data Acquisition and Processing System) project, a program to upgrade the data acquisition, processing and transmittal capability for test units J-4, J-5, and J-6. This system will double AEDC's rocket data capability from 250,000 aggregate samples per second to 500,000 aggregate samples per second.

The EDAPS program will support the latest in state-of-the-art rocket data acquisition. Some of the key features are the acquisition of thermal data using high resolution modular Digital UTRs, data acquisition from any independent data source such as the Military Standard 2553 electronic control bus or the AEDC PDCS3 high resolution pulse data acquisition system, an on-line calculated data display capability that can be reconfigured in real time, and data transmission directly to the mainframe processing computers over secure fiber optic links. The new system also allows independent

operation of the other rocket facilities, eliminating the constraint to schedule calibration and data acquisition activities between the rocket cells.

All of these features are designed to enhance productivity while reducing constraints and turn around times between tests.



Engine Test Facility Data Acquisition and Processing System (EDAPS) data screen.

Future AEDC Facility Upgrades

AEDC is planning several future upgrades to the AEDC rocket propulsion facilities to accommodate the anticipated requirements for outyear DOD, NASA, and commercial programs such as the Evolved Expendable Launch Vehicle (EELV), Reusable Launch System (RLV) and validation of foreign component performance, and upgrades to existing space lift and strategic launchers.

Upper stage engines in the small, medium, and heavy lift categories are being evaluated for technology improvements or new applications requiring altitude qualification. These engines use cryogenic, hypergolic, or tri-propellants to optimize performance for the specific application. Examples of technology insertion include new exhaust nozzles, control systems, and materials to improve altitude operational and economic performance.

While existing propellant support systems are in place to test typical upper stage cryogenic and hypergolic propellant engines, new propellant delivery systems are in planning to support the heavy lift engine requirements.

These engines are estimated to be in the 200,000 to 800,000 lbf thrust category. Outyear plans for supporting these test requirements include additions of large engine cryogenic propellant systems, upgrades of the data acquisition system, increased integration of plume phenomenology instrumentation, and automation and optimization of consumable systems to improve system reliability and performance.

AEDC is planning other modifications including systems to support complete upper stage mission duty cycle testing. This includes provisions for mounting complete stage structures, engine gimbaling, stage propellant delivery control and instrumentation systems, thermal conditioning, as well as loading, venting, and detanking systems.

All of these modifications are planned to maintain AEDC's position as the simulated-altitude test center of choice.

Related Facilities

AEDC is the nation's largest ground test center simulator of flight simulation test operating more than 50 separate facilities with altitude capabilities from sea-level to deep space conditions. In addition to rocket test cells, these facilities include space chambers, wind tunnels, arc heaters, ballistic ranges, nuclear effects facilities, and turbine test cells. Specific information on these facilities may be obtained from AEDC/DO or AEDC/PA. Of particular interest to launch vehicle developers are:

Environmental Space Chambers

Able to simulate deep space conditions up to 1.4×10^{-7} torr, AEDC space chambers vary in size to accommodate full-scale launch vehicle hardware as well as smaller components. MARK I, the largest chamber with a 42 foot diameter and 82 feet high, has been used for Titan 34D and Titan IV fairing separation tests, Small ICBM staging tests, and Minuteman penetration aids drop tests. The chamber can also be used to test space thrusters. Smaller chambers are used for smaller space thrusters, measurement of contamination effects, and verification of component-level mechanical and electrical systems.

Propulsion Wind Tunnels

AEDC operates 16-foot supersonic and transonic wind tunnels and a 4-foot transonic wind tunnel. The 16-foot tunnels are equipped with a scavenging system to remove exhaust products when testing propulsion systems. The tunnels have been used to test launch vehicle aerodynamics, plume interactions with the airstream, and tactical missiles.

Hypersonic Test Facilities

AEDC's uses a variety of hypersonic test facilities to assess vehicle performance. AEDC's aerothermal facilities are the highest-pressure arc-heated facilities in the U. S., providing unique, high-enthalpy environments for testing materials. Aerodynamic testing in the hypersonic regime is accomplished in Tunnels A, B, and C and in the Aeropropulsion Test Unit. The Hypervelocity Range G Facility can provide simulation of high stagnation enthalpy and pressures for ablation/erosion and aerodynamic testing of launch vehicle systems.

Advanced Missile Signature Center (AMSC)

The AMSC is a national archive of plume signature data for a variety of ballistic and tactical missiles. The AMSC employs a wide array of data analysis tools and JANNAF models to assess data quality and phenomena. Other resources include a complete video post-production facility and real-time video digitizing system, and a distributed computer system serving BMDO and SIPRNET classified networks.

Test Highlights
Rocket Propulsion



Titan IV fairing separation in MK I space chamber.

*Titan IV
aerodynamic
test in PWT
16T.*



*Space Shuttle in
PWT 16T.*



Arc Heater

Computer generated plume